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	Subsystem/Office Calorimeter Subsystem	

Document Title

CAL CsI Crystal Procurement Readiness Summary

Abstract

This technical note summarizes the procurement specification and controls of the LAT CAL CsI Crystal procurement and the supporting analyses, evaluations and tests which demonstrate that the specified item will meet the environmental and performance requirements of the Calorimeter Subsystem of LAT.

1 Introduction

The CAL team has about seven years of experience in developing the calorimeter design concept for LAT. This work has focused on Thallium doped Cesium Iodide detector elements read out by PIN photodiodes at each end. The concept of using a hodoscopic configuration of these detectors was first demonstrated in a beam test in 1997 at SLAC. These first demonstration calorimeters incorporated 30 x 30 x 190 mm CsI crystals manufactured by Horiba Inc.and readout with commercial PIN photodiodes manufactured by Hamamatsu. These detector elements were used in beam tests in 1996, 1997 and 1998 to demonstrate energy resolution and position resolution in a hodoscopic array.

As part of NASA's GLAST Advanced Technology Program (ATD), the concept of the basic detector element – the Crystal Detector Element (CDE) – was advanced to address the dynamic range in energy to meet the GLAST objectives. To achieve the ~10^6 in dynamic range, the crystal readout was divided into two signal changes each supported by a PIN diode. The ATD demonstration calorimeter module consisted of 8 layers of 10 CsI crystals. Approximately half of the CsI crystals were manufactured by Crismatek and the other half were manufactured by Amcrys-H. We found only minor differences in the performance of the crystals from the two vendors.

2 Referenced Documents

CsI Crystal Specification		
CAL CsI Crystal Performance Specification	LAT-DS-00820-03	11 Feb 2003
CAL CsI Crystal Drawing	LAT-DS-01115-01	20 Nov 2002
CAL CsI Crystal Specification	LAT-DS-00095-05	05 Apr 2001
CAL CsI Crystal Handling & Shipping Procedure	LAT-PS-00809-01	25 Jun 2002
Related Specifications		
CAL Flight Crystal Detector Element (CDE) Specification	LAT-DS-01133-02	20 Jan 2003
CAL Structure to CDE Interface Control Document	LAT-SS-00601-01	09 Aug 2002
Evaluation and Test Reports		
Performance of EM CsI(Tl) Crystals	LAT-TD-01599-01	24 Feb 2003
First Radiation Hardness Tests of CsI(Tl) Crystals from Amcrys H	LAT-TD-01213-01	10 Jan 2003
First Radiation Hardness Test of CDE CsI(Tl) Crystals	LAT-TD-01531-01	6 Feb 2003
LM2 and VM2 Tests Report	LAT-TD-00850-02	26 July 2002
LM2 Performance Test Results	LAT-TD-00616-01	10 Dec 2001

3 Responsibilities

The development of the CAL CsI Crystal requirements and specifications has been a joint responsibility of the Royal Institute of Technology (KTH, Sweden), Kalmar University (Sweden) and the Naval Research Lab. This development required critical participation from LLR/Ecole Polytechnique and CEA/DAPNIA in developing the requirements for the crystal detector element (CDE = crystal with bonded diodes on each end and optical wrap) and the CDE interfaces with the mechanical structure. The lead for the CsI crystal design and testing at Kalmar is Leif Nilsson. The leads for CDE design and testing issues are J. Eric Grove at NRL and Philippe Bourgeois at CEA. The leads for mechanical design and integration issues are Oscar Ferreira at LLR and Paul Dizon at NRL. Nick Virmani at NRL has lead responsibility for EEE parts, manufacturability and quality assurance issues.

The CsI crystal procurement for LAT is the responsibility of the Swedish GLAST Consortium lead by Per Carlson at KTH. Kalmar University provides the day-to-day technical interface with the CsI Crystal vendor, Amcrys-H, in the Ukraine. Kalmar has worked with Amcrys-H in developing manufacturing processes, will perform on-site inspections and quality control monitoring, will receive the flight crystals, perform acceptance testing and maintain traceability and data records. This work at Kalmar is under the direction of Staffan Carius and Leif Nilsson. KTH is responsible for the radiation testing of boule samples as part of the material acceptance process identified in the crystal procurement. Kalmar packs accepted material in CEA-provided shipping containers for delivery to CEA. These same shipping containers are later used for the delivery of completed CDEs to NRL.

4 Specifications

The Swedish GLAST Consortium selected Amcrys-H to provide all CsI crystals required in the development and flight unit fabrication for the LAT Calorimeter. A competitive selection process began in December, 2000, and the final selection of Amcrys-H occurred in February, 2001. The procurement specification evolved into the final contract specification – CAL CsI Crystal Specification, LAT-DS-00095-05 after negotiations with the vendor, Amcrys-H. The first prototype crystals were delivered in June, 2001.

In February, 2002, after a review of the CAL module design and associated component tolerances and their buildup, it was necessary to modify the crystal dimensions and specification to provide better margins to insure manufacturability of the modules. Several changes were made to the dimensions and definition of the chamfer on the crystal edges. These changes resulted in a revised specification, CAL CsI Crystal Performance Specification, LAT-DS-00820-03, (hereafter, PerfSpec) which essentially supersedes LAT-DS-00095 as far as mechanical and performance issues are concerned. The PerfSpec summarizes the changes from the original specification in section 5. Amcrys-H has agreed to all these changes and has just completed manufacture of 48 prototype crystals to the new specification.

The key specifications are summarized here:

	Issue	**Requirements / Comments**
Mechanical	Dimensions and tolerance Surface treatment	Flatness of surfaces, parallelism of opposing surfaces, perpendicularity of adjacent surfaces Polished surfaces with treatment for required light taper along crystal's length
Optical Performance	Light yield Light yield uniformity Light taper Radiation Hardness	Measured with Swedish provided test bench w/ Swedish test procedure. All crystals must have same yield +/- 10% End – to – end light collection requirement Verified on boule samples prior to manufacture of crystals from the boule. Sweden does the test
Shipping and Handling	Shipping Inspection and Tests	Containers, environmental protection, tracking and data records Acceptance testing, process control, quality provisions
Quality Control	Traceability	Amcrys-H process control and data records

Figure 1. Nine of the CDEs used in LM2 and VM2 test program.

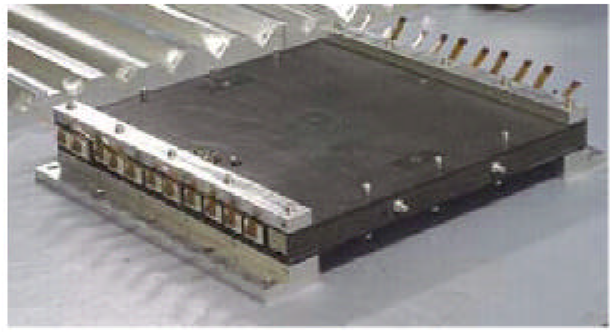

Figure 2. LM2 structure during assembly. Eleven of the CDEs have been inserted.

5 Qualification Plan

Thallium-activated Cesium Iodide, CsI(Tl), is on the CAL Inorganic Materials List and has recently been approved by NASA/GSFC for use in LAT. The specific use of CsI as specified in the PerfSpec to meet the environmental and performance requirements of the LAT Calorimeter has been demonstrated in several verification models and will be ultimately demonstrated with the CAL Engineering Model.

6 Verification and Testing

The verification and test program for the CAL module began in France with the development of prototype CDE using the first crystals manufactured to the LAT-DS-00095-05 specification. Figure 1 is a photograph of nine of the 12 CDEs used in this early testing. The CDEs consisted of a 333 x 26.7 x 19.9 mm CsI crystal with a dual PIN photodiode bonded to each end and wrapped in VM2000 reflective material. The electrical connections to the photodiodes were made with a flexible cable as seen in the photograph. These CDE were tested in two prototype structures, LM2 and VM2, which provided configurations for various test objectives. This test program was performed in France by CEA and LLR. As a result of this testing and additional design review, modifications were made to the dimensions and chamfers to improve manufacturability and to reduce risk in assembly. These changes are captured in the PerfSpec, LAT-DS-00820-03.

Approximately 250 crystals were manufactured to the original specification. These crystals were used in prototype testing in Sweden and France as well as crystals for two complete engineering models (96 crystals each). The first deliveries were used to develop CDE bonding process and to manufacture 12 CDEs used in the LM2 and VM2 testing.

Since these crystals had been manufactured before the changes incorporated in the PerfSpec, all had to be modified to meet the dimension and chamfer spec. These remaining crystals were machined to the new length, 326 mm, at Amcrys-H. However, Kalmar was responsible for correcting the chamfer. These modified crystals were used to manufacture CDEs for the EM CAL module.

The first prototype crystals (~50) manufactured to the PerfSpec have been recently shipped to Kalmar for verification.

6.1 LM2

LM2 (lab model 2) consists of a composite structure of 12 cells in 1 layer. Twelve active CDEs were placed in the cells. Aluminum closeouts simulated the remaining components of a CAL module. Figure 2 is a photograph of the LM2 configuration during assembly. The principle objective of the LM2 was to validate the CDE concept with respect to environment and performance requirements.

The LM2 objectives were to validate the CDE concept:

- Demonstrate that photodiode bonded with DC93500 silicone can survive handling during wrapping, integration inside the cells, removal from the cells.
- Demonstrate that bonding can survive qualification level mechanical and thermal loads when the CDE are mounted inside the cells with elastomeric cords and bumpers.
- Demonstrate that flex cable concept used for VM2 / LM crystals can survive handling of the logs and environmental loads.
- Demonstrate that light yield of CDEs, wrapped with VM2000 film, is not affected by environmental loads when the logs are mounted inside the cells.
- Demonstrate that light yield of CDEs, wrapped with VM2000 film, is not affected during insertion and removal of the logs from the composite cells.

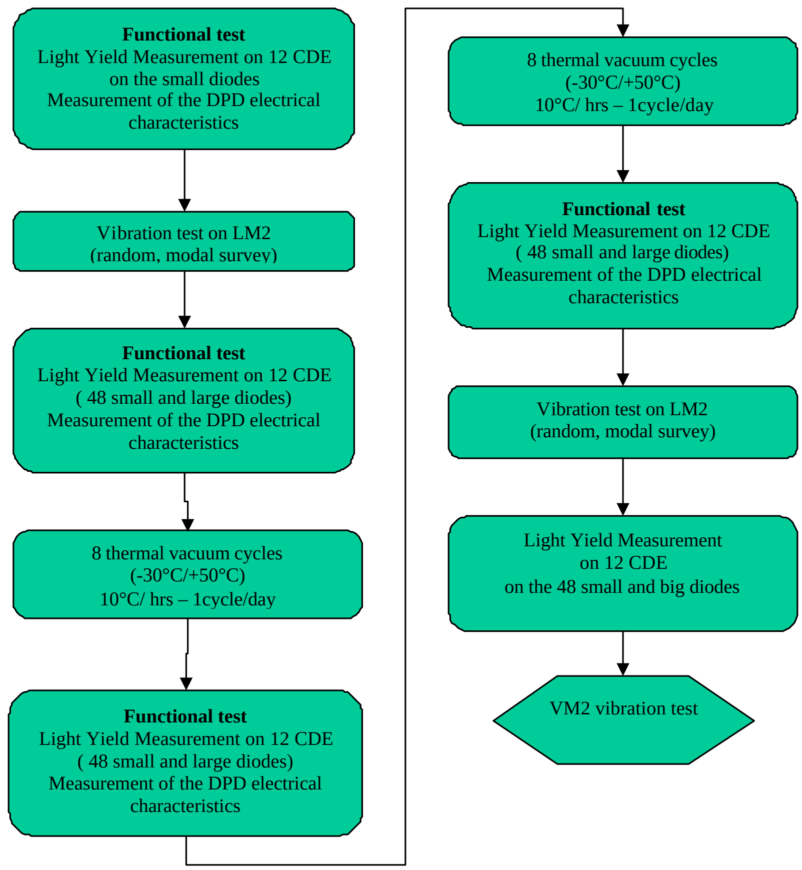

Figure 4. LM2 test sequence.

The general test sequence is outlined in Figure 4. More detailed descriptions of the tests and the results are found in the reports: “LM2 and VM2 Tests Report”, LAT-TD-00850-02, and “LM2 Performance Test Results”, LAT-TD-00616-01.

The insertion of the CDEs into the cells indicated the problem in controlling the chamfer and its impact on inserting the CDEs with the elastomeric bands along the chamfer – cell corners. A revised chamfer spec was developed and tested in the LM2 assembly process. Other than this change, the structure and CDE performed as expected and the performance of the CDEs was preserved throughout the test program.

6.2 VM2

VM2 (verification model 2) is a complete CAL mechanical structure consisting of a composite structure of 96 cells and aluminum parts (close-out plates, side panels, top frame, base plate). The CDE used in the testing were mostly mechanical or thermal dummies - dummy CDE in aluminum for thermal tests and in steel for the vibration tests. For the vibration tests, 9 active CDEs from the LM2 were installed in the structure. The AFEE boards were also simulated by dummy boards with a representative stiffness. Figure 3 is a photograph of the VM2 during assembly.

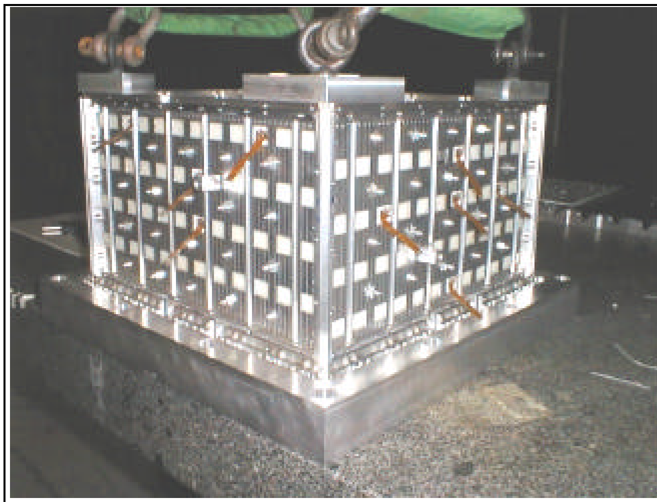

Figure 3. VM2 PreElectronics Module. Note the placement of nine active CDEs as seen by exposed flex cables. Remaining 87 CDEs were mass dummies.

The principle objective of the VM2 was to validate the mechanical structure concept of the CAL module with respect to environment requirements:

- Demonstrate that the design of the CAL structure meets the specifications in terms of stiffness: natural frequencies above 100Hz, deflections below 0.5 mm.
- Demonstrate that composite structures fabricated with current process are able to withstand both mechanical and thermal loads.
- Demonstrate that the concept used to hold the CDE preserves their safety and has no impact in their performance.
- Demonstrate that the current design of the mechanical structure is well matched with the dimensions of the crystal and that integration can be done without problem.

Figure 5 summarizes the test sequence of the VM2 module. Performance of the 9 active CDE was verified at the completion of the testing by returning them in the LM2 system. Results of the testing are found in "LM2 and VM2 Tests Report", LAT-TD-00850-02. No design problems were discovered.

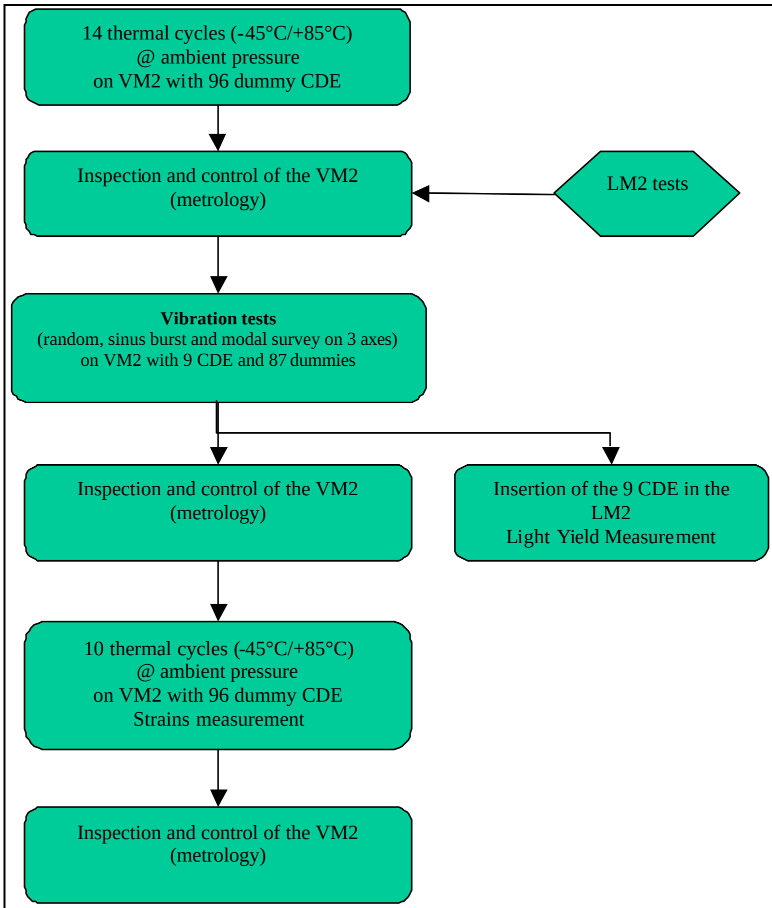

Figure 5. VM2 test flow.

6.3 Engineering Model

The CAL Engineering Model is currently in assembly. Ninety-six CDEs have been installed in the mechanical structure and the closeout plates have been installed. Figure 6 is a photograph of one of the CDEs delivered by CEA for the EM assembly. It also shows the protective V-block used in shipping to support and protect the crystal. For the EM, 124 CDEs were manufactured – 110 at NRL and 14 at CEA. All of these CDE were manufactured from CsI crystals that had been reprocessed to the new specification in the PerfSpec.

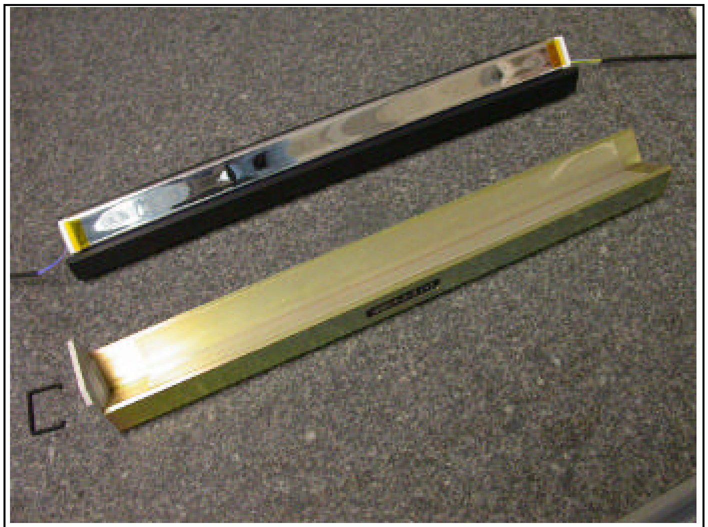

Figure 6. CDE (top) and shipping V-block.

The EM CDE specification is found in LAT SS-00239-04. The light yield for the EM CDEs was found to be 8500 e/MeV. This is compared with the CAL Level IV spec of >5000 e/MeV. This significantly greater than spec'ed yield is caused by the larger area of the low energy PIN diode and the improved light yield associated with the VM2000 wrapping on the CDE.

Details of the performance testing of the EM CDE and the correlation with the CsI crystal performance is summarized in LAT-TD-01599-01.

6.3.1 Radiation Testing

Boules are tested before any CAL crystals are manufactured from a boule. See, for example, LAT-TD-01213-01.

Correlation of boule sample results to CAL CDE results are in report LAT-TD-01531-01.

All radiation tests indicate that the boule samples meet the requirements in LAT-DS-00095-05 and LAT-DS-00820-03. The tests on the CDE show the expected response and fully meet the design requirements for the CAL CDE, LAT-DS-01133-02.

Proton irradiations will be performed April 7th.

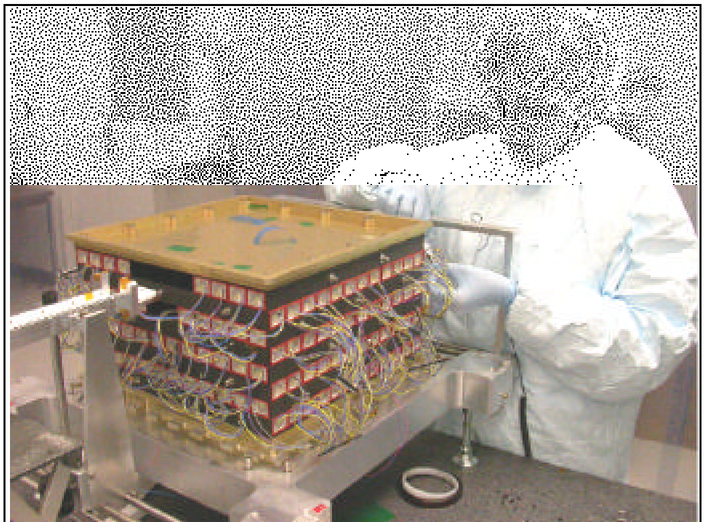

Figure 7. EM CAL during CDE insertion into structure. Red compression bumpers are added to the ends of each CDE.

6.4 Flight Model Configuration

The modifications to the flight CsI crystals are minimal and have all been tested by re-machining the original EM crystals. The modifications are two: 1) reduce the length to 326 mm, and 2) apply a new chamfer definition which is related to the actual size of individual crystals – ie. control the separation of diagonally opposite chamfers. The PerfSpec and crystal drawing, LAT-DS-01115-01, incorporate all these changes.

Approximately 50 crystals manufactured from scratch to the new specifications have been received in Kalmar and are in acceptance testing. These crystals will be delivered to CEA for inspection and CDE bonding process development.

7 Procurement Issues

Table 1. Estimate of Required CsI Crystal Quantities

CDE	**Required CDE for Flight**			**1728**
	Flight Spares	6.4%	110	1838
	CEA Delivery to NRL			**1838**
	Acceptance Test Failures	1.0%	19	1857
CsI	**CsI for CDE Acceptance Test**			**1857**
	Bonding Process Fallout	2.0%	38	1895
	Spare CsI	0.0%	0	1895
	Dimensional Fallout	0.0%	0	1895
	CsI Flight Prototypes/ Bonding Development		50	1945
	TOTAL CsI Requirement			**1945**
	Prototype Procurement			50
	Flight Procurement			1895

The flight crystal procurement is in place as part of the single contract with Amcrys-H for development , EM crystals, and flight crystals. This contract has been modified as required to meet the changing specifications and crystal quantities during the development phase. All changes have been confirmed between the Swedish Consortium and Amcrys-H.

7.1 Quantity

Table 1 summarizes the estimated requirements for the number of flight crystals needed to execute the CAL manufacturing plan. The table works backwards from the number of CDE required for flight and associated spare CDE that are delivered to NRL. From that point, it summarizes the assembly steps and estimates the material losses at each step.

One of the largest losses is the fallout from bonding failures to the CsI. If a bond has bubbles, it is rejected. We expect that generally the CsI crystal of a failed bond lay-up can be recovered by removing the diode and cleaning/polishing the CsI surface, the DPD involved in the bad bond will likely be lost. Some crystals will be damaged beyond use in this cleaning process and will be discarded. We have estimated a 10% bonding failure rate for loss of diode. The table shows a much smaller rate for bonding failure crystal loss.

The table includes the 50 flight prototype crystals for process verification and bonding studies.

8 Risk Assessment

There are no significant outstanding technical risks associated with the CsI crystals. The acceptance test verification of the flight prototypes will be complete in 2 weeks.

CAL carries a minor risk in the single source contract for all flight crystals. If some mishap at the Amcrys-H factory or some customs/political change occurs in the Ukraine, the delivery schedule of flight crystals could be significantly delayed.

While multiple vendors are available to manufacture CsI to our specification, we have no plans in place to use them. Our risk mitigation is to start manufacturing well before crystals are needed at CEA and continue deliveries at 200 crystals per month. The current schedule has all crystals delivered well before the end of calendar 2003. The later deliveries are as much as 6 months before need.

9 Summary

The testing to date show that the CsI crystals as defined in the PerfSpec will meet the requirements of the LAT CAL. The completed assembly of the EM CAL module shows compatibility of the CDE (including CsI Crystal) with the mechanical structure. Environmental testing of the EM CAL will verify this compatibility to qualification levels.